Historic, Archive Document

Do not assume content reflects current scientific knowledge, policies, or practices.

Methyl Bromide *Alternatives*

USDA

Vol. 10, No. 1
2004

Inside This Issue

This issue and all back issues of the *Methyl Bromide Alternatives* newsletter are now available at **http://www.ars.usda.gov/is/np/mba/mebrhp.htm**. For additional information, visit the ARS methyl bromide research homepage at **http://www.ars.usda.gov/is/mb/mebrweb.htm**.

This newsletter provides information on research for methyl bromide alternatives from USDA, universities, and industry.

Address technical questions to Nancy Ragsdale, USDA, ARS, National Program Staff, 5601 Sunnyside Ave., Beltsville, MD 20705-5139. Phone (301) 504-4509, fax (301) 504-5987.

Address suggestions and requests to be added to the mailing list to Sharon Durham, USDA, ARS, Information Staff, 5601 Sunnyside Ave., Beltsville, MD 20705-5129. Phone (301) 504-1611, fax (301) 504-1641.

Greenhouse-Grown Bell Pepper Production

Bell pepper growers in Florida, and perhaps other areas of the country, have a viable alternative to growing them in the field. During the 2002-2003 growing season, 17,800 acres of bell peppers were planted and mostly green bell pepper fruits (mature but unripe stage of fruit development) were harvested from these field crops. Colored bell pepper fruits (ripe) attract market values that are three to five times greater than green fruits, but high fruit quality and yield of colored fruits are difficult to obtain in open field environments.

High-quality colored bell peppers can, however, be produced year round and especially during the high-priced off seasons, in protected environments such as high passively ventilated greenhouses. Fruits can be harvested with red, orange, or yellow color depending on the pepper cultivar used. Indeed, essentially all of the high-quality and high-value colored bell peppers imported to the United States are grown in greenhouses. In Florida, a small number of growers already produce high-quality colored fruits in an area of about 45 acres.

During the past 6 years, University of Florida scientists at the Protected Agriculture Project, lead by Daniel J. Cantliffe, have been examining the production of greenhouse-grown peppers in Florida (http://www.hos.ufl.edu/protectedag/). Scientists Elio Jovicich, Daniel J. Cantliffe, John J. VanSickle, Lance S. Osborne, Nicole L. Shaw, Peter J. Stoffella, Steven A. Sargent, and Margaret L. Smither-Kopperl examined the production of greenhouse-grown peppers in Florida. "The initial impetus for this research was to explore which greenhouse and management practices for pepper would work best in Florida," says Jovicich. "We wanted to adapt what other countries were using and found that greenhouse roofs needed to be high to provide ventilation and allow cooling, shade systems and supplemental fuel heating were needed, and fertigation could be done in containerized plants filled with low-cost soilless media."

In the United States, the consumption of high-quality red, orange, and yellow bell peppers (*Capsicum annuum*) has been increasing dramatically the past decade. To satisfy consumer demand, Mexico, The Netherlands, Canada, Israel, and Spain export high-quality greenhouse-grown peppers into

the United States. In Florida, high market prices, consumer demand, and a suitable environment for growing colored peppers under protected agriculture have encouraged greenhouse growers to consider the economic viability of this crop.

The impending ban on methyl bromide, along with greater demand for high-quality colored peppers, may give growers a reason to consider growing peppers in greenhouses. Other pressures include urban sprawl and subsequent high prices for arable land. For the past 5 years, pepper ranked first in production area in Florida's total greenhouse area dedicated to vegetable crops (followed by tomato, cucumber, and lettuce).

Jovicich, VanSickle, Cantliffe, and Stoffella simulated a full production of greenhouse-grown peppers under a passively ventilated structure in Florida using management practices necessary to successfully grow peppers and turn a profit. The estimates indicate that production of greenhouse-grown peppers could represent a viable vegetable production alternative for Florida growers and possibly for growers in other regions of the United States.

A greenhouse production system of peppers greatly differs from the traditional field pepper cultivation system where plants are grown on polyethylene-mulched beds and with drip irrigation. In greenhouses, high fruit yield and quality are produced in a small area during an extended growing season. Moreover, soil sterilization is not needed, and water and nutrients that drain from the bottom of the plant containers can be recycled. The enclosed environment also makes the use of biological control practices for pest management more effective than in open fields, actually allowing the production of fruits that are pesticide-free.

Marketable fruit yields will vary with greenhouse location, growing season, plant density, trellis system, cultivar, irrigation, and fertilizer management. Current marketable yields of 1.6 to 3.0 lb. per square ft. and potential yields of 4 lb. per square ft. can be obtained in Florida in passively ventilated greenhouses with low use of heating fuel. "However, because of the higher costs involved with greenhouse growing systems compared to growing in the open field, greenhouse growers have to manage their crops to maximize fruit yield and quality while minimizing production costs per unit of greenhouse floor area," says Jovicich.

Greenhouse Structures

In Florida, there is currently a trend towards using high-roof, passively ventilated greenhouse structures (13 ft. or more to the roof gutter) for protected vegetable production.

The greenhouses are covered with polyethylene, which is replaced every 3 to 4 years. The side walls and roof vents can be covered with insect screens to restrict the entrance of pest insects and to keep beneficial insects, such as bumblebees, within the greenhouse.

"These high-roof greenhouse designs are less expensive and more suited for use in regions with subtropical and tropical climates than structures covered with glass or polycarbonate," says Jovicich. "Costs of passively ventilated greenhouses can range as much as 80% less per square ft. than the types of greenhouses that seek maximum climate control." Greenhouses with passive ventilation and heating provide a level of climate control that enables plants to survive and produce at economically sufficient yields.

Cultivars

Sweet pepper cultivars most commonly used in greenhouse production are hybrids that have bell-shaped or blocky-type fruits with red, orange, or yellow color when mature. "Cultivars should be selected for a grower's ability to market them, as well as pest and disease resistance or tolerance, low susceptibility to fruit disorders, and yield and quality performance," says Jovicich. Some of the commonly used cultivars are Parker, Triple 4, Cubico, and Lorca for red, Kelvin for yellow, and Neibla and Emily for orange fruits. However, new pepper cultivars for greenhouse production are introduced by seed companies every year.

In a pepper cultivar trial conducted in a passively ventilated greenhouse in Gainesville, Florida, the total marketable yield was acceptable for 23 cultivars tested when grown and harvested during the winter months in north central Florida, according to a study by Shaw and Cantliffe in 2002. The red and yellow cultivars produced fruit yields of 1.8 to 2.2 lb. per

square ft. and the orange cultivars had yields of 1.4 to 2 lb. per square ft. When comparing cultivars for those with the highest yield and fruit quality characteristics with low amounts of culls or other disorders, the best red cultivars in the study were Lorca, Torkal, Triple 4, and Zambra; yellow cultivars were Pekin, Kelvin, Neibla, Bossanova, and Taranto; and orange cultivars were Paramo, Lion, and Boogie.

Growing Seasons

The most common greenhouse pepper production season extends from mid-July or early August to May. Long crops of up to 300 days are transplanted during the second or third week of July with a first harvest around the middle of October, ending in late May. Depending on fruit prices and on the quantity and quality of the fruits harvested, production may be extended until June.

High temperatures and humidity during July and August adversely affect production but are good for young plant growth. With some cultivars, percentages of unmarketable fruits increase during the late spring mainly due to a higher incidence of blossom-end rot and fruit cracking. Fruit set can also be low during the summer due to high rates of flower abortion under high temperatures. Air ventilation and shade materials for 30% shade help reduce high temperatures during the late spring, summer, and early fall. Currently, water misting is being evaluated as a cooling system for plants transplanted in the summer. Cold weather during winter can also adversely affect the set of marketable fruits due to poor pollination and delay maturation and earliness in production. "In central and northern Florida, optimum daytime temperatures required for pepper production can easily be achieved in winter while optimum night temperatures cannot, and therefore, heating during the night is necessary to increase fruit yield and improve fruit quality," says Jovicich.

Soilless Culture Systems

Greenhouse pepper crops in Florida are grown in soilless culture. Methyl bromide is not needed since problems with soil-borne diseases and insect and nematode pests are avoided. The plants are grown in containers filled with soilless media, such as perlite, pine bark, or peat mixes. The media can be reused for two or three crops if disease contamination does not occur. The containers used are nursery pots (3 and 4 gallons) with one plant per pot. Another planting scheme uses flat polyethylene bags that are 3 ft. long (5 gallons) with 3 to 4 plants per bag. The plant containers can be aligned in single or double rows, one next to the other, and can lead to plant population densities of 0.27 to 0.36 plants per square ft.

In local trials with greenhouse-grown peppers, fruit yields from plants grown in 3-gallon pots or 5-gallon flat bags have been similar. Also, similar marketable fruit yields were harvested from plants grown in various substrates, such as perlite, pine bark, or peat-perlite mixes. "Pine bark, milled, and sieved to particle sizes smaller than 1 square inch, have shown to be a promising medium in Florida because of its low cost, availability, lack of phytotoxicity, and excellence as a plant production media," says Jovicich.

Irrigation and Fertilization

Pepper plants in soilless culture are fertigated frequently with a complete nutrient solution. Nutrient solution concentrations are similar to those used for tomatoes grown in soilless culture. The concentrations of most of the nutrients required by pepper plants in larger quantities are increased with plant growth. For example, in the irrigation solution used with soilless culture, the concentration of nutrients in parts per million (ppm) can be N:70, P:50, K:119, Ca:110, Mg:40, and S:55, starting when transplanting the seedlings. In plants at full production, the nutrient concentration levels can reach N:160, P:50, K:200, Ca:190, Mg:48, and S:65 ppm, respectively.

At the time of transplanting, seedlings can be irrigated about 10 times a day and deliver about 1.3 fluid ounces per irrigation event. As plants grow and season temperatures rise, irrigation frequency and volume per irrigation event can be increased up to 40 times a day and deliver about 2.5 fluid ounces per irrigation event.

Systems for recycling the fertigation solution are available and provide a more sustainable use of water and nutrients. "With these 'closed' irrigation systems, the solution that drains from the pots is sanitized and then the pH and EC are corrected to meet the plant needs. Subsequently, the nutrient

solution can be recycled on the same pepper crop," says Jovicich.

Transplanting, Pruning, and Training

Transplanting of plants is also a bit different in greenhouse production. Frequent irrigation and high levels of salt deposits near the cotyledonary node level can promote localized epidermal injuries on a swollen stem base and fungal infection can lead to basal stem rots and sudden plant wilts. To avoid injuries to the plant stem below the cotyledonary leaves, seedlings should be transplanted into the soilless culture substrate to the depth of the first leaf node. To reduce creating a humid environment at the base of the stem, irrigation emitters that are placed near the seedling stems at transplanting can be gradually moved back 2 to 3 inches from the base of the pepper plants over a 3-week period.

Greenhouse pepper cultivars generally have an indeterminate pattern of growth. Because the plants can grow up to 6 ft. tall during a growing season of 250 days, they need to be supported vertically. Pepper plants can be trellised to the Dutch "V" system or to the "Spanish" system. The "V" system consists of forming a plant with two main stems by removing one of the two shoots developed on each node and leaving one or more adjacent leaves per node. The pairs of stems are kept vertically by the use of hanging twines that wind around the stems as they grow.

In the "Spanish" trellis system, the plant canopy is allowed to grow without pruning. The plants are vertically supported by a structure of poles and horizontal twines extended on both sides of the plant rows. Labor requirement for the "Spanish" system is reduced minimally by 75% of the labor used compared with the "V" trellis system. In a study where the two trellis systems were compared, the percentage of fruits with blossom-end rot at the end of the spring was lower in the non-pruned plants.

Pollination

While pepper plants are self-pollinated, the use of bumblebees inside the greenhouse help to ensure the set of high-quality fruits, especially during the cool season when pollen viability is lower. "Although one bumblebee hive (containing 60 bees) per 16,000 square ft. might seem costly to the grower, pollination done by workers would be less efficient and much more expensive," says Jovicich. "The hive should be placed under a shade in summer and in the sun in winter and isolated from ants. The hives should contain a supplement food for the bees during periods of low abundance of flowers because over-visited flowers may lead to fruits with cork-like spots at the blossom-end."

Harvesting and Packing to Maintain Postharvest Fruit Quality

Throughout the harvest season, pepper fruits ripen in flushes or waves of production. Under warm environments, fruits can be picked once or twice a week at close to full color. Nonmarketable fruits should be removed from the plants as soon as they are observed. Clipped peduncles keep a better appearance during shipping and handling and cause fewer injuries to adjacent peppers.

Marketable fruits are graded by diameter, and fruits with greater size bring higher prices. Fruit grades can follow the USDA standards for field-grown peppers or classifications based on diameter ranges similar to greenhouse peppers imported from Holland (extra-large, diameter more than 3.3 inches; large, 3 to 3.2 inches; medium, 2.5 to 2.9 inches; and small, 2.2 to 2.3 inches).

Peppers should not be submerged in water during the transfer to the packing line since water can easily infiltrate the hollow pod and cause postharvest decay. The use of overhead spray with clean water and brush rollers works well for washing.

Pepper fruit respiration can be delayed by quickly cooling the product to the lowest safe temperature of 48 to 50° F and 90 to 95% relative humidity, resulting in a postharvest life of 2 to 3 weeks. Rapid cooling of harvested sweet peppers is essential in reducing marketing losses. Forced-air cooling is the preferred method.

Pre-cooling within a few hours of harvest and storage in a high relative humidity will minimize weight loss and shrivel symptoms, and maintain firmness. Waxing provides some surface lubrication, which reduces chafing in transit. Water loss can also be limited by packing cooled peppers into cartons with moisture-retentive liners

or into perforated polyethylene bags.

Pests and Diseases

Pests are reduced but not eliminated in screened greenhouse structures. Transplants must be free of pests and weeds must not be present inside the greenhouse. "The major arthropod pests observed in greenhouse peppers in Florida are broad mite (*Polyphagotarsonemus latus*), two-spotted mite (*Tetranychus urticaae*), western flower thrips (*Frankliniella occidentalis)*, melon thrips (*Thrips palmi*), green peach aphid (*Myzus persicae*), melon or cotton aphid (*Aphis gossypii*), silverleaf or sweet potato whitefly (*Bemisia agentifolii*), pepper weevil (*Anthonomus eugenii*), fungus gnats (*Bradysia* spp.), and several lepidopterous pests."

Fungal diseases that may be present are powdery mildew (*Leveillula taurica*) and Fusarium (*Fusarium oxysporum* and *F. solani*).

Insecticides are available to control insect and mite pests. However, many chemicals negatively affect bumblebees, beneficial organisms, and the pepper plant itself. Some products, such as soaps, oils, and sulfur, are often phytotoxic to pepper plants in the greenhouse.

Biological control practices used in other regions and crop systems are being evaluated by researchers in the Protected Agriculture Project at the University of Florida and at the Mid-Florida Research and Education Center.

Compared to the use of pesticides, with biological control, insects do not develop the resistance that they do to certain insecticides. Also, restricted reentry period to the greenhouse due to the use of insecticides are eliminated, the environment for workers is safer, and harvest products can be labeled "pesticide free," which may bring higher prices and/or increase consumer demand. The use of biological controls will require that the crop is scouted frequently to determine presence and to estimate population densities of crop damaging pests and their natural enemies.

The production of greenhouse-grown peppers represents an alternative crop in Florida, and ongoing research by the Protected Agriculture Project continues on greenhouse-grown peppers on production systems, fruit quality, cultivars, nutrient and water management, integrated pest and disease management, postharvest, and marketing.

Non-Fumigant Measures and Assessment of Host Tolerance for Replant Disease Control

Apple replant disease is a continuing problem for growers in Washington. Ongoing studies have identified cultural and biologically active methods that provide partial control of the pathogen complex that incites apple replant disease in Washington.

Mark Mazzola, a plant pathologist with USDA's Tree Fruit Research Laboratory in Wenatchee, Washington, conducted studies that have identified soil amendments effective in controlling certain elements of the causal pathogen complex and have demonstrated the ability to enhance growth of apple on replant sites.

When applied independently, these control practices have improved vegetative growth and enhanced yield of apple (Gala/M.26) in orchard trials; however, these individual treatments did not achieve the level of disease control and crop yields realized in response to pre-plant soil fumigation. "It is apparent that the synthesis of multiple control methods has significant potential to achieve levels of disease control and tree growth and yield that is comparable to that obtained through pre-plant soil fumigation," says Mazzola.

Subsequent field trials indicate that *Brassica napus* seed meal was applied as a soil amendment in the fall prior to planting in conjunction with a post-planting application of the fungicide. Ridomil (metalaxyl) has significant potential as an alternative to pre-plant soil fumigation for the control of apple replant disease. The post-plant fungicide application is required due to the increased activity of *Pythium* spp. in response to this soil amendment. The Malus germplasm has been shown to vary in tolerance to the biological complex that incites replant disease, according to a 2000 paper by D.K. Isutsa and I.A. Merwin. The current study has identified tolerance within commercially available rootstocks to specific elements of the causal disease complex. These findings indicate that host tolerance will be an important element to consider during the design of a systems ap-

proach to the management of apple replant disease.

Treatments were established in 2000 and 2001, and trials were planted to Gala/M26 and Golden Delicious/M7 in the spring of 2002 at the Wenatchee Valley College-Airport (WVC) and Columbia View (CV) Orchards, respectively. Treatments included application of *B. napus* seed meal in the fall prior to planting in conjunction with solarization, wheat cropping in varying sequence, or a Ridomil soil drench at 2 weeks post-planting. The target pathogen complex at the CV orchard includes *Cylindrocarpon destructans*, *Phytophthora cactorum* and *Ph. syringae*, *Pythium heterothallicum* and *Py. intermedium*, and *Rhizoctonia solani* AG-6. Causal agents at the WVC site include *C. destructans*, *Ph. cactorum*, *Py. sylvaticum*, *R. solani* AG-5, and *Pratylenchus penetrans,* a nematode.

Tolerance of commercially available apple rootstocks toward *R. solani* AG-5, and *P. penetrans* was assessed in greenhouse assays. Relative growth of rootstocks in replant orchard soils was assessed in field trials at the CV orchard.

Mazzola found that *B. napus* seed meal amendments, in conjunction with a Ridomil soil drench and Telone-C17 soil fumigation, were effective in controlling the pathogen complex that was targeted at the WVC and CV orchards. Over the initial 3-year life span of the CV orchard, growth of Gala/M26 planted in seed meal/Ridomil-treated soil has been equivalent to that of trees established in fumigated soil. In addition, initial yields from trees receiving this alternative treatment has exceeded those obtained in response to soil fumigation (table 1). Wheat cropping followed by seed meal amendment and solarization also enhanced tree growth relative to the control, but both were inferior to soil fumigation. At the WVC orchard, 16-month growth of Golden Delicious/M7 has been enhanced relative to the non-treated control by all alternative treatments evaluated, with the exception of soil solarization. However, alternative treatments have provided a growth response that is inferior to that obtained with pre-plant soil fumigation.

"I certainly think this regimen is feasible for growers," says Mazzola. "The cost is about $100 to $150 per ton, applied at 3.8 tons per acre. *B. napus* seed meal is also a good source of nitrogen, at about 6%, which can reduce fertilizer inputs."

Apple rootstocks exhibited considerable difference in tolerance toward the fungal pathogen *R. solani* AG-5 (table 2). Among the rootstocks evaluated, M.7 and Bud.9 were consistently the most susceptible, regardless of the soil in which assays were conducted, and tree death was commonly observed. In contrast, Seedling and Geneva16 rootstocks exhibited the greatest tolerance to this pathogen. Geneva16 has also demonstrated significant tolerance/resistance to the lesion nematode, while M.9, MM106, and MM111 supported significantly higher populations of this plant parasitic nematode.

Follow-up trials established in 2004 are investigating the incorporation of host tolerance/resistance as an additional element within the context of the integrated disease management system. As *B. napus* seed meal may function through the activity of specific microorganisms that colonize apple roots, selection of a specific rootstock may have multiple influences on the success of such a disease control strategy.

Table 1. Impact of pre-plant soil treatment on yield of Gala/M26 established on a replant site at the Columbia View Research and Demonstration Orchard in May 2002

Treatment	2003 yield (kg fruit/tree)	2004 yield (kg fruit/tree)
Control	0.00 az	5.8 a
Telone-C17	0.83 b	13.3 lb
B. napus meal/Ridomil	2.89 c	13.6 lb
Wheat/*B. napus* meal	0.42 ab	8.98 a
Solarization	0.23 ab	8.46 a

Values followed by the same letter are not significantly ($P = 0.05$) different.

Table 2. Relative tolerance of selected apple rootstocks to *Rhizoctonia solani* AG-5 and *Pratylenchus penetrans* as assessed by growth relative to that obtained in the absence of pathogen or root populations

Rootstock	% (growth in the presence of *R. solani* relative to the control)	*P. penetrans* (# / g root)
Seedling	113	151 bcz
Bud.9	51	76 ab
Geneva16	103	23 a
M.7	55	366 de
M.9	100	362 de
M.26	41	262 cd
MM106	67	621 f
MM111	72	484 ef

Values followed by the same letter are not significantly ($P = 0.05$) different.

U.S. Critical Use Exemptions

The ban on methyl bromide use for the United States will take full effect in January 2005 with certain exceptions. Growers, however, may be able to use the fumigant on a limited basis if a Critical Use Exemption (CUE) is sought and granted.

Methyl bromide, come January 2005, will be banned except for CUEs, quarantine and pre-shipment exemptions, and emergency exemptions.

CUEs are, quite simply, allotments given to agricultural sectors so growers and other producers will be able to legally use methyl bromide in the absence of economical, practical, and efficacious alternatives.

CUE allocations are proposed to be handled according to information recently available on the EPA website at http://www.epa.gov/ozone/mbr/index.html.

Technical Reports

An Apparatus to Inject Soil Fumigants Under Raised, Plastic-Mulched Beds

Dan O. Chellemi, USDA-ARS, Fort Pierce, FL
e-mail: dchellemi@ushrl.ars.usda.gov
John Mirusso, Mirusso Fumigation and Equipment, Delray Beach, FL

Abstract

An Under Bed Fumigator was designed, fabricated, and tested for injecting soil fumigants underneath raised planting beds covered by plastic mulch without disturbing the integrity of the beds. Two opposing armature systems mounted on a tractor tool bar at a 15° angle were used to deliver fumigants to the center of plastic-mulched beds. Using a virtually impermeable plastic mulch, uniform concentrations of a fumigant mixture of 1,3-dichloropropene and chloropicrin were spread across the beds. The Under Bed Fumigator mitigates worker exposure to fumigants by separating land preparation activities from the fumigant application process. It provides growers without access to drip irrigation the opportunity to disinfest soil before planting a second (double) crop in existing mulched beds. Effective control of soilborne pests was obtained when the Under Bed Fumigator was used to fumigate previously established beds prior to the planting of a cucumber double crop.

Introduction

Pre-plant soil fumigation is a critical component of high-value crop production systems, including fresh market tomato and pepper (Noling 1997, Wilhelm and Paulus 1980). Florida is the leading producer of fresh market tomato and pepper in the United States, where these crops have a combined annual farmgate value of $751 million (NASS 2004). Crops are cultivated on 15- to 30-cm high by 70- to 100-cm wide beds that have been fumigated and covered with polyethylene mulch. Fumigants are shank-injected using chisels spaced 30 cm apart as the soil is being pulled up to form the beds (Gilreath et al. 1999, Jones et al. 1995, Locascio et al. 1997). Beds are then covered immediately with polyethylene plastic, which functions as a mulch. The soil fumigant methyl bromide has been used almost exclusively by these industries since the 1970s, but its use has been subjected to a mandatory phase-out due to environmental concerns (U.S. EPA 2004).

Florida fresh market tomato and pepper production accounts for 24% of the methyl bromide consumed in the United States for soil fumigation (U.S. EPA 1997). Without a suitable replacement, economic losses have been projected to exceed $1 billion (Spreen et al. 1995). Several studies have identified a mixture of 1,3-dichloropropene and chloropicrin (1,3-D + Pic) as the best alternative fumigant to methyl bromide (Gilreath et al. 1999, Jones et al. 1995, Locascio et al. 1997). In the past, concerns over exposure

of workers present in the field during plastic-laying operations restricted its application potential. In order to minimize human exposure, application technology is needed to separate plastic-laying operations from the application of fumigants. Fumigants may be applied to plastic-mulched beds via drip irrigation (Ajwa et al. 2002). However, many growers in Florida still cultivate their crops with seepage irrigation systems and cannot easily convert to drip irrigation technology.

Reducing fumigant application rates without compromising their efficacy can be achieved by extending the exposure time of pest propagules to the fumigant (Munnecke and Van Gundy 1979). One way this can be accomplished is by trapping the fumigant in the soil. While polyethylene plastic films offer little resistance to fumigant diffusion, new virtually impermeable films (VIF) are available (Gan et al. 1998, Papiernik et al. 2001, Wang et al. 1998, Yates et al. 1997, Yates et al. 2000). For growers who do not use drip irrigation systems, an apparatus to inject fumigants under established VIF-mulched beds would expand the use of this technology.

The objective of this research was to design, fabricate, and test an apparatus for injecting soil fumigants under existing raised, plastic-mulched beds. Success of this research would improve the potential of 1,3-D + Pic as a replacement for methyl bromide and maximize the benefits of VIF technology.

Materials and Methods

Description of the apparatus. The fumigation system, referred to as the Under Bed Fumigator, consisted of a tractor, a fumigant tank, a nitrogen gas cylinder, a toolbar with weights, and two opposing armature systems for injecting fumigants underneath the plastic-mulched beds. Fumigant and nitrogen tanks were mounted on the front of the tractor. The armature systems and weights were mounted to the toolbar. Nitrogen was used to push the fumigant from the fumigant reservoir to the armature systems. Each armature system included a main arm assembly, a hub and spindle assembly, a close-wheel assembly, and a fumigant dispersal assembly. Armatures were mounted to the toolbar at an angle to permit the fumigant dispersal assembly to reach under the planting bed without disturbing the integrity of the bed shoulders. In preliminary trials, an angle of 10° to 20° facilitated optimum fumigant injection and minimized stress on the injection blade. An angle greater than 20° caused disturbance to the plastic mulch and placed additional stress on the hub and spindle assembly. An angle less than 10° caused the fumigant to disperse into the unmulched areas located between the raised beds. Mounting the armatures at 0° did not allow the fumigant or injection blade to reach up into the bed and place the injection blade at a horizontal position, subjecting it to extreme stress from the resistance of the soil as it was dragged through the field and increasing the potential for bending or breaking the blade.

For the main arm assembly, any arm assembly from a commercial coulter system could be used. The Under Bed Fumigator used a main arm assembly system obtained from a Yetter 30 Avenger (Yetter Farm Equipment, Colchester, IL). The arm assembly was modified to permit attachment of the assembly to the toolbar at angles between 10° and 20° by welding a plate and mounting a bracket to the toolbar. The mounting bracket also included a shim placed between the attachment plate of the arm assembly and the toolbar to create a 5° variation in the horizontal direction of each armature. This changed the width of the knife groove (opening in the soil created by the coulter blade) and reduced drag of the assembly.

For the hub and spindle assembly, any assembly from a commercial coulter system could be used. The hub and spindle assembly used for this apparatus was also obtained from a Yetter 30 Avenger. A 76-cm coulter was attached to the spindle assembly to create a track for the fumigant delivery assembly to enter the soil while minimizing disturbance to the soil profile.

The fumigant dispersal assembly consisted of a knife, blade, and conduit tube attached to the support bracket. The knife was 40-cm long, 12-cm wide, and had a contoured surface roughly conforming to the arc of the circular perimeter of the coulter blade. The knife tip was blunt, permitting field debris to clear under the knife. A blade was permanently attached to the inner side of the knife at a 90° angle and 2.5 cm from the bottom of

the knife. The outer-facing edge of the blade was flush with the rear-facing edge of the knife. The inner edge of the blade was 9-cm wide and the outer end was 5-cm wide. The blade was beveled with a 2-cm double kerf. A conduit delivered fumigant from the fumigant tank to the main arm assembly of the armature. A 3-mm stainless steel fumigant feed tube was welded to the back edge of the knife and the outer edge of the blade and delivered the fumigant from the main arm assembly to an orifice located 2 cm from the blade tip.

Field evaluations. Two experiments were conducted at the USDA Header Canal Research Farm (St. Lucie County, FL). The soil type was a Riviera fine sand (loamy, siliceous, hyperthermic, and Arenic Glossaqualfs). Soil organic matter was 1.7%; soil pH 7.4; and the soil texture was 96% sand, 2% silt, and 2% clay. Soil moisture at the initiation of experiments ranged from 6.7% to 9.0% by weight.

The first experiment was designed to determine the distribution of a fumigant under different plastic mulches following their application with the Under Bed Fumigator. A 61%:35% mixture of 1,3-dichloropropene plus chloropicrin (Telone C-35, Dow AgroSciences, Indianapolis, IN) was applied at 327 l ha^{-1} under beds covered by polyethylene (white over black, co-extruded, embossed, and 30-µm thick, Pliant Corporation, Schaumburg, IL) or virtually impermeable (white over black, triple-extruded, smooth, and 35-µm thick, Hytibarrier Flex, Klerks Plastics, Hoogstraten, Belguim) plastic mulch. The fumigant was applied using the Under Bed Fumigator. Four beds 30 m in length were prepared for each plastic type. Beds were arranged on 2-m row centers. Bed dimensions were 102 cm at the base and 91 cm at the top. Beds were 25-cm high and were pressed prior to applying the plastic with a single-row plastic layer. Raised beds were prepared and covered with plastic and then fumigated on August 19, 2002.

The concentration of 1,3-dichloropropene plus chloropicrin in the soil atmosphere was measured after removing a 2.5 x 12.5 cm soil core and sampling the airspace. Total concentrations were estimated using a GasTec Model GV-100 Gas Sampling Pump (Sensidyne Inc., Clearwater, FL) with Gastec 132HA trichloroethylene detector tubes (GasTec Corp., Ayase-City, Japan). Concentrations were adjusted using a 2X correction factor as recommended by the manufacturer. Samples were collected for 1, 2, 3, 4, 7, 10, and 18 days after fumigant application at six locations on both edges of the bed, 20 cm from both edges of the bed, the center of the bed, and in the furrow (unmulched area between each raised bed). Four samples were collected for each location on each sample date.

The second experiment was designed to measure the efficiency of the Under Bed Fumigator in delivering fumigants at lower application rates. A 61%:35% mixture of 1,3-dichloropropene plus chloropicrin was applied at 94, 187, and 280 l ha^{-1} under beds covered by virtually impermeable plastic mulch (white over black, triple-extruded, smooth, and 35-µm thick, Hytibarrier Flex). The fumigant was applied using the Under Bed Fumigator. Four beds 30 m in length were prepared for each plastic type. Beds were arranged on 2-m row centers. Bed dimensions were 102 cm at the base and 91 cm at the top. Beds were 25-cm high and were pressed prior to applying the plastic with a single-row plastic layer. Raised beds were prepared and covered with plastic and then fumigated on August 26, 2002. Fumigant concentrations were measured as described previously after removing a 2.5 x 12.5 cm soil core from the center of the bed and sampling the airspace. Four samples for each application rate were collected 4 and 10 days after application.

Field validation. To test its feasibility and durability, the Under Bed Fumigator was used to treat 0.5 ha of a commercial tomato production farm located in St. Lucie County, Florida. To access its effectiveness, the incidence of soilborne pests and marketable yields were compared to adjacent areas of the farm fumigated with a 67:33 mixture of methyl bromide: chloropicrin at 448 kg ha^{-1}. Beds in the test area were prepared and covered with a virtually impermeable plastic mulch (white on black, smooth, 35-m thick, 'Bromostop', Industria Plastica Monregalese, Mondovi, Italy) on August 6, 2003. Beds in the methyl bromide-treated areas were prepared, fumigated, and covered with a high-density polyethylene plastic mulch (white on black, embossed, 20-m thick,

Sonoco Plastic Co., Orlando, FL) on August 6. Bed dimensions were 76-cm wide by 25-cm wide. On August 12, a 61%:35% mixture of 1,3-dichloropropene plus chloropicrin was applied at 327 l ha^{-1} under beds covered by the virtually impermeable plastic using the Under Bed Fumigator. Tomato seedlings (*cv.* Florida-47) were transplanted into the beds on September 6. Plots were harvested on November 17 and 28 and the marketable yield was determined. Plots were rated for the incidence of soilborne disease and weed populations on December 9.

Results and Discussion

The final configuration of the Under Bed Fumigator was determined after multiple tests were conducted over an 18-month period. The performance of the Under Bed Fumigator was assessed at tractor speeds up to 8 km per hr. No disruption to the integrity of the beds was observed and the apparatus was not damaged by repeated applications. The number of weights mounted above the toolbar was varied to compensate for differences in soil types and moisture.

The fumigant mixture of 1,3-dichloropropene plus chloropicrin was detected between the beds (in the furrow) and the row middles up to 4 days after application. Concentrations in the furrow were highly variable (0 to 500 ppm) and peaked 1 day after application. No fumigant was detected in the row middles after 4 days. Movement into the row middles may have been caused by a horizontal gap in the soil profile created by the blade or by abrupt changes in the depth of the fumigant placement due to uneven field terrain.

In beds covered by the polyethylene mulch, concentrations of 1,3-D plus chloropicrin peaked 2 days after application. Concentrations were highly variable through the soil profile. The highest fumigant concentration was measured at the edge of the bed, where it reached an average level of 840 ppm. Fumigant concentrations declined to 480 ppm 20 cm from the edge of the bed and only reached 220 ppm in the center of the bed. No fumigant could be detected in the soil 7 days after application.

In beds covered by the virtually impermeable mulch, concentrations of 1,3-dichloropropene plus chloropicrin peaked at 900 ppm 4 days after application. Because chloropicrin has a half-life in soil of less than 24 hr, it was assumed that the concentration of fumigant in the soil after 4 days was primarily 1,3-D. At 10 days after application, fumigant concentrations were still greater than 250 ppm. Fumigant concentrations in the bed were uniform after 4 days and remained uniformly distributed at 10 days after application. By 18 days after application, no fumigant could be detected in the beds.

Using an application rate of 94 l ha^{-1}, 250 ppm of 1,3-dichloropropene plus chloropicrin was detected in the center of beds covered by a virtually impermeable plastic mulch. Thus, the Under Bed Fumigator was able to deliver fumigants to the center of the planting beds when the application rate was reduced by 72%.

Differences in fumigant concentration and distribution under the two types of plastic were related to the permeability of the plastic. Polyethylene films are highly permeable to fumigants, including methyl bromide and 1,3-dichloropropene (Gan et al. 1998, Yates et al. 1997). By contrast, VIF films are up to 1,000 times less permeable to methyl bromide and 1,3-dichloropropene than high-density polyethylene films (Papiernik et al. 2001, Wang et al. 1998). The VIF films used in this study have been reported to be 1 million times less permeable to 1,3-dichloropropene than high-density polyethylene (Papiernik et al. 2001). Thus, under the polyethylene mulch, most of the fumigant migrated vertically through the soil profile and passed directly through the plastic into the atmosphere.

In the field validation test, the Under Bed Fumigator performed under commercial conditions without compromising the application procedure or the integrity of the planting beds. No phytotoxicity to the transplanted tomato seedlings was observed. The marketable yield of plants grown in beds fumigated with methyl bromide:chloropicrin and covered with a polyethylene plastic mulch was 29,680 kg ha^{-1}. The marketable yield of plants grown in beds where the Under Bed Fumigator was used to apply 1,3-dichloropropene:chloropicrin under beds covered by a virtually impermeable plastic mulch was 32,256 kg ha^{-1}. Thus, under commercial conditions, an 8% increase in marketable yield was achieved using the Under Bed Fumigator to apply a fumigant alternative

to methyl bromide under a virtually impermeable plastic mulch. Weed populations in the test area and methyl bromide-treated area remained less than 1 per 10 m of row. The incidence of *Fusarium* wilt (a soilborne fungal disease caused by *Fusarium oxysporum f. sp. lycopersici* Race 3) was 9.0% in the methyl bromide fumigated beds and 4.7% when the Under Bed Fumigator was used to apply 1,3-dichloropropene:chloropicrin under beds covered by a virtually impermeable plastic mulch.

One additional use of the Under Bed Fumigator that has not been thoroughly explored is its use to disinfest beds prior to planting a second crop. Although successive cropping of existing mulched beds is recommended to make effective use of the polyethylene mulch and fumigant (Simonne and Hochmuth 2001), rapid increases in pathogen, nematode, and weed populations during cultivation of the first crop prevent re-use of the beds for a second (double) crop. Shank injection of fumigants into existing plastic-mulched beds is not possible using the standard application equipment. The Under Bed Fumigator may have additional application potential in this area.

Conclusion

The Under Bed Fumigator was developed to apply fumigants under established raised beds covered by plastic mulch. Its application potential was validated in a 0.5 ha trial conducted in a commercial tomato production field. Its use is recommended for small- to medium-scale producers of horticultural and ornamental crops with raised-bed, plastic-mulch production systems. The Under Bed Fumigator mitigates regulatory hurdles associated with worker exposure and the use of personal protective equipment by separating the fumigant application from land preparation activities. It also allows growers to make more efficient use of their production fields by creating opportunities to disinfest soil in fields that do not have access to fumigant injection through drip irrigation systems. A patent application was submitted to the U.S. Patent & Trademark Office on October 3, 2002 (Serial No.: 10/263, 107 and Docket No.: 0113.02).

Chloropicrin and Inline Dose-Response Under VIF and HDPE Film: Weed Control Results in California

S. Fennimore[1], Z. Kabir[1], H. Ajwa[1], O. Daugovish[2], K. Roth,[1] and J. Valdez[1]
[1]University of California, Davis, Salinas, CA 93905
[2]University of California, Ventura, CA 93003

Virtually impermeable films (VIF) have been tested for several years. These films may reduce fumigant emissions and increase fumigant efficacy by retaining lethal fumigant concentrations for longer times. However, we know of no field dose response studies to evaluate whether VIF improves fumigant efficacy on weeds. The objective of this work is to determine if VIF improves the weed control efficacy of chloropicrin (Pic) and Inline under VIF and standard film.

Methods

Pic and Inline were applied at 50, 100, 200, 300, and 400 lbs per acre in water through the drip irrigation system on September 16, 2002 near Oxnard, CA and on October 1, 2002 near Watsonville, CA. Methyl bromide/chloropicrin (MBPic) was shank-applied at 350 lbs per acre. Two types of film were used: standard high-density polyethylene (HDPE) and VIF (Bromostop). Each treatment was replicated four times and arranged in a randomized complete block design. Gas permeable bags containing yellow nutsedge tubers were buried 6 inches deep in the center of the beds prior to fumigation and retrieved prior to strawberry transplanting. Similarly, bags containing burclover, common chickweed, common purslane, little mallow, and knotweed seed were buried at 2 and 6 inches deep in the center and at the edge of the bed prior to fumigation. After retrieval, the nutsedge samples were germinated in greenhouse pots to test viability and weed seed viability was determined with tetrazolium. Strawberry 'Camarosa' was planted on October 7 at Oxnard and on October 25 at Watsonville. Weed counts, weed fresh weights, and weeding times were measured within 100 ft long subplots on November 26, 2002, January 15, February 25, March 26, and May 8, 2003 at Oxnard and within 90 ft long subplots at Watsonville on December 5, 2002, February 24, April 3, and May 1, 2003.

Results and Discussion

Tarp type did not affect native weed biomass and weeding times at Oxnard (table 1). However, at Watsonville, VIF reduced native weed biomass and weeding times (table 2). Impermeable films appear to improve weed control with Inline more than Pic. At Watsonville, weeding times with Inline at 200 lbs per acre were 40 hours per acre under VIF and 91 hours per acre under HDPE (table 2). Generally, Pic and Inline killed more chickweed, knotweed and purslane seed under VIF than under HDPE (tables 3 and 4). Based on 50% growth reduction (GR50), the Inline doses at Oxnard required to kill half the nutsedge samples were 101 lbs per acre (80, 122, lower and upper 95% confidence intervals, respectively) under VIF and > 400 lbs per acre under HDPE. Nutsedge GR50s at Watsonville for Inline were 147 (137, 156) under VIF and 262 (236, 295) under HDPE. The GR50s for Pic at Oxnard on nutsedge were 185 lbs per acre (156, 216) under VIF and 362 lbs per acre (288, 515) under HDPE. Nutsedge GR50s for Pic at Watsonville were 128 lbs per acre (121, 136) under VIF and 218 lbs per acre (194, 247) under HDPE.

Conclusion

These results suggest that Inline and Pic generally provide better weed control under VIF than HDPE. VIF improves control of difficult-to-control weeds, such as yellow nutsedge, compared to HDPE.

Table 1. Efficacy of chloropicrin and Inline fumigants applied under VIF and HDPE films on native weed biomass and weeding times at Oxnard, CA[1]

Fumigants	Dose (lb/A)	Biomass (kg/A)		Weed time (hr/A)	
		VIF	HDPE	VIF	HDPE
		---------------kg/A-----------------		----------------hr/A-----------------	
Control	0	546.4 a	581.0 a	109.8 a	114.8 a
Chloropicrin	50	242.8 bcdef	332.8 bcde	84.4 bc	94.3 b
	100	281.9 bcdef	266.5 bcdef	73.7 cdefg	73.7 cdefg
	200	387.6 b	198.5 cdef	76.5 cde	63.6 efgh
	300	161.2 ef	158.4 ef	60.4 efgh	57.4 gh
	400	149.3 ef	210.4 bcdef	51.8 h	58.7 fgh
Inline	50	336.9 bcde	360.7 bcd	74.0 cdefg	81.9 bcd
	100	217.4 bcdef	281.0 bcdef	69.3 cdefgh	76.1 cdef
	200	122.2 f	237.1 bcdef	57.1 gh	65.2 defgh
	300	129.2 f	228.7 bcdef	55.4 h	66.8 defgh
	400	135.2 f	172.7 ef	54.9 h	57.6 gh
MBPic	350	372.1 bc	178.0 def	68.5 cdefgh	54.5 h

[1] Means within the biomass columns or within the weed time columns followed by the same letter do not differ at 0.05, according to the Duncan's multiple range test.

(Editorial Note: Treatments sharing a common letter in the biomass or weed time columns are not statistically different. For example, the controls show the letter "a" and thus are statistically different from the treatments; therefore, the treatments are effective.)

Table 2. Efficacy of chloropicrin and Inline fumigants applied under VIF and HDPE films on native weed biomass and weeding times at Watsonville, CA[1]

Fumigants	Dose (lb/A)	Biomass (kg/A)		Weed time (hr/A)	
		VIF	HDPE	VIF	HDPE
		----------------kg/A----------------		----------------hr/A----------------	
Control	0	2014.5 a	2098.2 a	245.0 a	257.9 a
Chloropicrin	50	1069.9 bc	1322.3 b	150.4 bcd 1	87.2 b
	100	601.8 def	1059.3 bc	132.2 cde 1	70.7 bc
	200	463.4 defg	678.1 cde	102.4 efgh	117.4 def
	300	352.0 efg	494.1 defg	62.4 hijk	84.5 fghij
	400	271.3 efg	413.4 efg	48.8 ijk	82.5 fghij
Inline	50	647.5 de	1334.0 b	112.5 defg	169.4 bc
	100	265.2 efg	873.3 cd	62.6 hijk	117.5 def
	200	185.5 fg	471.6 defg	40.2 jk	91.4 efghi
	300	110.2 g	393.2 efg	42.2 jk	70.7 ghijk
	400	112.1 g	317.9 efg	35.7 k	71.4 ghijk
MBPic	350	300.0 efg	340.3 efg	56.4 hijk	60.6 hijk

[1] Means within the biomass columns or within the weed time columns followed by the same letter do not differ at 0.05, according to the Duncan's multiple range test.

(Editorial Note: Treatments sharing a common letter in the biomass or weed time columns are not statistically different. For example, the controls show the letter "a" and thus are statistically different from the treatments; therefore, the treatments are effective.)

Table 3. Efficacy of chloropicrin and Inline fumigants applied under VIF and HDPE films on weed seed viability at Oxnard, CA [1]

Fumigants	Dose (lb/A)	Chickweed		Knotweed		Purslane	
		VIF	HDPE	VIF	HDPE	VIF	HDPE
		----------------viability (%)----------------					
Control	0	97 a	96 a	97 a	95 ab	100 a	99 a
Chloropicrin	50	88 ab	92 a	96 ab	97 ab	93 a	99 a
	100	78 abc	81 abc	95 ab	94 ab	79 ab	86 ab
	200	15 hij	48 defg	63 gf	80 bcde	15 ef	42 cd
	300	21 hij	35 gh	58 g	76 cdef	21 def	38 cd
	400	0 j	45 fg	33 h	79 bcdef	0 f	38 cd
Inline	50	68 bcd	97 a	89 abcd	97 a	91 a	99 a
	100	47 efg	83 abc	74 defg	97 a	66 b	98 a
	200	19 hij	66 cde	25 hi	90 abcd	31 cde	80 ab
	300	0 j	63 cdef	13 ij	92 abc	12 ef	80 ab
	400	0 j	32 ghi	3 j	69 efg	0 f	44 c
MBPic	350	0 j	13 ij	0 j	25 hi	0 f	29 cde

[1] Means within weed species columns followed by the same letter do not differ at 0.05, according to the Duncan's multiple range test.

(Editorial Note: Treatments sharing a common letter in the biomass or weed time columns are not statistically different. For example, the controls show the letter "a" and thus are statistically different from the treatments; therefore, the treatments are effective.)

Table 4. Efficacy of chloropicrin and Inline fumigants applied under VIF and HDPE films on weed seed viability at Watsonville, CA[1]

Fumigants	Dose (lb/A)	Chickweed		Knotweed		Purslane	
		VIF	HDPE	VIF	HDPE	VIF	HDPE
		viability (%)					
Control	0	76 a	83 a	50 ab	58 a	97 a	95 a
Chloropicrin	50	37 b	31 bc	39 c	47 bc	41 cd	40 cd
	100	22 bcd	27 bc	44 bc	46 bc	34 de	31 de
	200	6 e	11 de	16 def	27 d	0 f	12 f
	300	0 e	8 de	6 fg	21 d	1 f	9 f
	400	0 e	0 e	0 g	8 efg	0 f	0 f
Inline	50	9 e	35 b	19 d	47 bc	52 bc	66 b
	100	1 e	16 cde	5 fg	18 de	9 f	36 cd
	200	2 e	0 e	1 g	8 efg	5 f	13 f
	300	0 e	11 de	1 g	16 def	5 f	19 ef
	400	0 e	0 e	0 g	5 fg	1 f	10 f
MBPic	350	0 e	0 e	0 g	1 g	0 f	0 f

[1] Means within weed species columns followed by the same letter do not differ at 0.05, according to the Duncan's multiple range test.

(Editorial Note: Treatments sharing a common letter in the biomass or weed time columns are not statistically different. For example, the controls show the letter "a" and thus are statistically different from the treatments; therefore, the treatments are effective.)